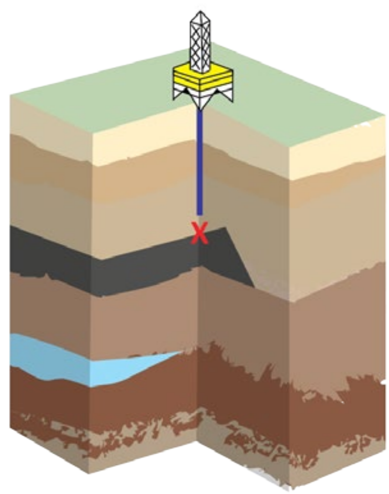
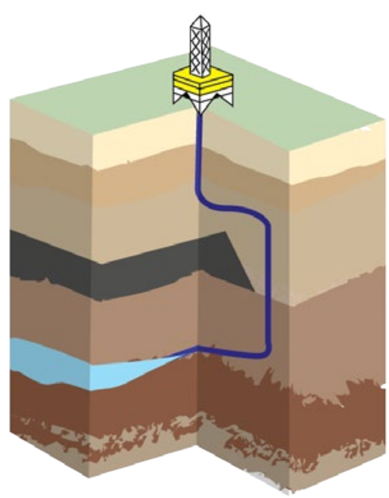
Calibration

Multi-dimensional calibration of measurement-while-drilling tools

Application Note



Vertical drilling creates linear boreholes that run downward, perpendicular to the Earth's surface. This type of drilling is suitable for simple jobs.



Directional drilling allows downward extension into two or three spatial dimentions. This type of drilling is suited for more complex jobs.

Application

In the oil and gas industries, the drilling process has become more exacting and therefore more complex. Professionals who work in these industries have multiple options for how to drill, and those options drive the need to make accurate measurements. For the "directional" method of drilling, measurement-while-drilling (MWD) tools provide important assistance to the measurement process. This application note explains some of the complexities in calibrating an MWD tool and also suggests some solutions for getting the job done.

Background

For simple jobs, vertical drilling may suffice. As its name implies, vertical drilling creates linear boreholes that run downward, perpendicular to the Earth's surface. Vertical drilling is often inefficient, because it cannot access horizontally distributed reservoirs effectively, nor can it circumvent underground impasses.

For more complex jobs, directional drilling may be a more useful solution. Developed in the 1920s, directional drilling introduced additional degrees of freedom to well creation, allowing downward extension into two or three spatial dimensions. This more sophisticated technique has successfully realized tremendous value from otherwise inaccessible resources.

An obvious technical challenge in directional drilling is ensuring that its complex drilling systems can operate continuously without disruption, despite having to traverse formidable conditions. The difficulty in controlling this extremely dynamic process is compounded by the thousands of miles that separate operators from their downhole extremities.

The MWD tool utilizes in-situ sensing technology that provides operators with critical downhole visibility, which has revolutionized directional drilling reliability. MWD tools capture real-time measurements to monitor the internal and external conditions of the drilling system. Some of the most valuable feedback from the MWD tool is based upon its hydraulic pressure measurements, which allow operators to closely monitor the health of the drilling system. This, in turn, helps them to avoid costly mechanical failures.

But, to ensure operators are provided with reliable information, the MWD tool must first be calibrated.

MWD tool calibration

It has been said that most pressure transducers also make great thermometers. This saying alludes to the fact that, although pressure transducers are designed to respond only when subjected to a change in pressure, they actually also respond to changes in ambient temperature. Consequently, the uncontrollable downhole temperatures that envelope an MWD tool will certainly compromise its critical pressure measurements—unless the appropriate considerations are made.

Transducer output is sensitive to changes in both applied pressure and ambient temperature.

Luckily, a pressure transducer responds to ambient temperature in a way that is repeatable and can be expressed mathematically. Therefore, when calculating pressure values, it is possible to create a calibration equation that jointly considers both the transducer's output and its ambient temperature. If constructed properly, this equation can effectively factor out distortions in transducer output resulting from ambient temperature variations.

To generate a calibration equation that renders accurate pressure measurements over a range of temperatures, the calibration process must subject the transducer to the same range of pressures and temperatures that it will see in service and record its outputs across these ranges. The resultant data can be used to derive the relationship among pressure and temperature versus transducer output, allowing for a multi-variable calibration equation to be generated.

The calibration begins by fixturing the MWD tool into the test oven, connecting the pressure reference, and measuring a zero reference point (ideally at Standard Pressure and Temperature). The oven is then elevated to a known temperature and a "soak time" allows the internal temperature of the tool to equilibrate. Once its temperature has stabilized, the entire range of nominal pressures is applied and the corresponding transducer outputs are recorded. Then, the temperature is further elevated and the range of nominal pressures reapplied; the process of temperature elevation and subsequent pressure measurement is repeated until the series of nominal pressures has been applied over the entire range of temperatures.

Multi-dimensional calibrations: manual versus automated

Although this advanced calibration method greatly improves the reliability of downhole pressure measurements, it takes a lot more time than a traditional one-dimensional calibration. The additional time required is indeed a "necessary evil" of multi-dimensional calibrations, as math insists that exponentially more nominal test points are required to achieve a given level of transducer characterization.

	Pressure					
Temperature	0%	20%	40%	60%	80%	100%
0%	0	1	2	3	4	5
20%	6	7	8	9	10	11
40%	12	13	14	15	16	17
60%	18	19	20	21	22	23
80%	24	25	26	27	28	29
100%	30	31	32	33	34	35

(Nominal Test Points)

To characterize a transducer using 20 % of scale increments, one-dimensional calibration would require six total test points while a two-dimensional calibration would require 36 total test points.

	Pressure										
Temperature	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	0	1	2	3	4	5	6	7	8	9	10
10%	11	12	13	14	15	16	17	18	19	20	21
20%	22	23	24	25	26	27	28	29	30	31	32
30%	33	34	35	36	37	38	39	40	41	42	43
40%	44	45	46	47	48	49	50	51	52	53	54
50%	55	56	57	58	59	60	61	62	63	64	65
60%	66	67	68	69	70	71	72	73	74	75	76
70%	77	78	79	80	81	82	83	84	85	86	87
80%	88	89	90	91	92	93	94	95	96	97	98
90%	99	100	101	102	103	104	105	106	107	108	109
100%	110	111	112	113	114	115	116	117	118	119	120

(Nominal Test Points)

Characterizing a transducer in 10 % of scale increased the total required test points to 11 for a one-dimensional calibration and 121 for a two-dimensional calibration.

For example, a one-dimensional calibration designed to evaluate transducer linearity often uses nominal test points designated at 20 % of scale increments, requiring six total test points: a zero point followed by five nominal points. A similar calibration also evaluating transducer linearity in 20 % increments but across two dimensions (e.g. pressure and temperature) now requires 36 total test points. Tightening these characterizations to 10 % of scale increments causes the one-dimensional calibration to require 11 total test points, while calibrating across two dimensions requires 121.

Performing a multi-dimensional calibration with a manually-operated deadweight tester like this one is a daunting task.

For high performance plus automation, a piston gauge system like this Fluke Calibration PG7000 Piston Gauge can be an ideal pressure reference.

Based on these numbers, it becomes evident that performing a multi-dimensional calibration with manually-operated equipment is daunting.

A summary of a manual MWD tool calibration:

- After zeroing, a given tool needs to soak at an elevated temperature for 1.5 hours to stabilize
- An operator uses an industrial deadweight tester to generate 10 pressures and record each transducer output, taking about an hour
- The process is repeated until the entire range of temperatures had been achieved

A manual test run checking 10 nominal pressures at five nominal temperatures requires roughly 13 hours, presuming a technician is always available to generate pressures immediately after each soak time.

Finally, after the calibration equation has been calculated and uploaded into the MWD tool, this test run should be repeated—at least in part—to verify the accuracy of the calibrated device.

Because of the prolonged soak times and large number of nominal test points, automating this process is highly desirable. Automation reduces a typical run from greater than 13 hours to less than nine hours.

Since an automated calibration only requires operator attention at its start and finish, periodic trips back to the test station are now eliminated; this allows a technician to reallocate roughly five working hours to other important tasks. And, because increasing the duration of an automated calibration does not require additional labor, nominal test points and dwell times can be conveniently increased to improve transducer characterization and reliability.

This obviously begs the question, how can I automate my pressure calibrations?

Automating MWD pressure calibrations

The centerpiece of most automated pressure calibrations is an automated pressure controller like this Fluke Calibration 7250LP Low Pressure Controller/Calibrator.

The centerpiece of most automated pressure calibrations is an automated pressure controller. These pressure references can generate loads from vacuum pressure, through inches of water, up to 40,000 psi (275 MPa) with uncertainties that are typically better than ± 0.02 %. Supporting a variety of communications schemes, Fluke Calibration automated pressure controllers conveniently allow for process automation without sacrificing precision.

When a lab still wants to enjoy the efficiency gains of automation but needs to realize ultimate performance, a piston gauge system featuring an automated mass handler can

A temperature data logger such as this Fluke Calibration 1586A Super-DAQ can serve as the temperature reference, while also capturing measurements from the devices under test.

replace the automated pressure controller as the pressure reference. Fully automated with remote control, these systems can generate loads of over 70,000 psi (500 MPa) with uncertainties in the single-digit parts per million.

The temperature measurements required to fully characterize the DUT can be automated by employing a precision temperature scanner like the 1586A Super-DAQ. With up to 40 input channels, the 1586A can measure and record data from the temperature reference(s), DUT, and an array of probes monitoring the stability and uniformity of the test chamber.

Clearly, performing a multi-dimensional calibration requires additional consideration and expertise. So when you are faced with an application that demands this level of performance, call on the experience of the Fluke Calibration experts.

Fluke Calibration. *Precision, performance, confidence.*™

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